ELECTROPHORETIC DISPLAY ACTIVATION FOR MULTIPLE WINDOWS

This invention relates generally to electrophoretic displays, and more specifically to addressing a subwindow within an array of electrophoretic pixels.

Nonvolatile electrophoretic display media store digital information in the form of viewable text or images. Electrophoretic displays are generally characterized by the movement of polarized or charged particles in an applied electric field, and can be bi-stable with display elements having first and second display states that differ in at least one optical property such as lightness or darkness of a color. In recently developed electrophoretic displays, the display states occur after microencapsulated particles in the electronic ink have been driven to one state or another by an electronic pulse of a finite duration, and the driven state persists after the activation voltage has been removed.

An exemplary electrophoretic display with microcapsules containing either a cellulosic or gel-like phase and a liquid phase, or containing two or more immiscible fluids are described in "Process for Creating an Encapsulated Electrophoretic Display," Albert et al., U.S. Patent No. 6,067,185 issued May 23, 2000 and "Multi-Color Electrophoretic Displays and Materials for Making the Same," Albert et al., U.S. Patent No. 6,017,584 issued January 25, 2000.

Electrophoretic displays receive image data and may be addressed by driving an active matrix located on the frontside or backside of the display. The active-matrix displays have intrinsic addressing schemes such as fixed coordinates on a pixel-by-pixel grid to accurately write text and graphics. An exemplary electrophoretic display unit comprises a layer of electrophoretic ink with a transparent common electrode on one side, and a substrate or a backplane having pixel electrodes arranged in rows and columns. The crossing between a row and a column is associated with an image pixel that is formed between a pixel electrode and a portion of the common electrode. The pixel electrode connects to the drain of a transistor, of which the source is electrically coupled to a column electrode and of which the gate is electrically connected to a row electrode. This arrangement of pixel electrodes, transistors, row electrodes and column electrodes jointly forms an active matrix. A row driver supplies a row selection signal via the row electrodes to select a row of pixels and a column driver supplies data signals to the selected row of pixels via the column electrodes and the transistors. The data signals on the column electrodes correspond to data to be displayed, and form, together with the row selection signal, driving signals for driving one or more pixels in the electrophoretic display.

Electrophoretic ink, also referred to as electronic ink or e-ink, is positioned between the transparent common electrode and the pixel electrodes and typically comprises multiple microcapsules having a diameter between about 10 and 50 microns. In one example of a black-and-white display, each microcapsule comprises positively charged white particles and negatively charged black particles suspended in a fluid. When a negative electric field is applied from the pixel electrode to the transparent common electrode, the negatively charged black particles move towards the common electrode and the pixel becomes darker to a viewer. Simultaneously, the positively charged white particles move towards the pixel electrode on the backplane, away from the viewer's sight.

Applying an activation voltage between pixel electrodes and the common electrode for specified periods of time generally creates grayscale in an active-matrix monochromatic electrophoretic display. For a characteristic active-matrix electrophoretic display of current art, pulse-width modulation on a frame-by-frame basis may use, for example, a column driver with three voltage levels: -15 volts, +15 volts and 0 volts.

One method for driving an active-matrix display and controlling gradations of pigment particles is described in "Method and Circuit for Driving Electrophoretic Display and Electronic Device Using Same," Katase, U.S. Patent App. 2002/0021483 published February 21, 2002. In the method, a reset voltage is applied to each pixel electrode, then an applied voltage for writing to the display is applied to each pixel electrode, and then a common voltage is applied to each pixel electrode so that electric charge accumulated in each capacitor is taken away and a displayed image is held.

Electrophoretic displays have favorable attributes of good brightness and contrast, wide-viewing angles, high stability for two or more optical states, and low power consumption when compared to those of liquid crystal displays (LCDs). Additionally, the average power consumption of electrophoretic displays is much lower than that of LCDs due to the lower required refresh rate.

A description of how driving voltage may be reduced is given in "Method of Producing a Substrate Structure for a Large Size Display Panel and an Apparatus for Producing the Substrate Structure," U.S. Patent No. 4,775,549, Ota et al., granted in October 4, 1988. The application of driving voltage is reduced when a pixel equivalent capacitance is kept larger than the capacitance of a nonlinear element or switching element itself. The holding time of voltage applied to a selected pixel may be extended with a parallel capacitance, which may contribute to a low-voltage drive or high-speed response.

One attempt at controlling the brightness of the display and reducing deterioration caused by electrode reaction or electrolysis without drop in contrast is presented in "Migration Time Measuring Method and Electrophoresis Display Device," Hideyuki, International Patent No. JP9006277 granted in January 10, 1997. A time-control device is used to apply and drive voltage, and a sensor stops the driving voltage when its output corresponds to the saturated value of the brightness previously measured.

A lower refresh rate results from the bi-stability of the electrophoretic material, which can hold an image substantially on the display without supplying any voltage pulse. The voltage pulse is only needed during next image update. Furthermore, no updating or refreshing of a pixel and concomitant driving voltage are needed when the optical state of the p ixel does not change during the next image update, resulting still lower power consumption.

However, in current electrophoretic displays, the optical state of a pixel may drift away during an un-powered image-holding period or dwell time, especially in the first 100 seconds following an image update. The brightness decreases as the waiting time increases. This image instability makes it difficult to achieve good image quality for the window of the display, particularly when subwindows are created on the display, such as for dictionary applications where a definition of a word appears in a subwindow when a cursor points to a word in a displayed text.

Generally, the background window is not updated during addressing the subwindow in order to avoid optical flicker and save power. Thus, the pixels outside a subwindow have some remaining image-holding time when the subwindow is addressed. When a drive waveform optimized for a fixed dwell time is used for updating the subwindow, a brightness difference between the subwindow and the background window exists. The difference depends strongly on the image stability of the electronic ink and the image-holding time, which is variable from user to user and dependent on usage mode. The visible and undesirable image retention or ghosting may be evident when multiple subwindows are used or when the display experiences multiple or long dwell times, which are often unavoidable in practical applications.

Therefore, what is needed is an improved addressing method and associa ted system for multiple display windows of an electrophoretic display that provide the brightness of a newly addressed child window or subwindow to optically match the background of the parent or main window already in an unpowered condition. In addition, a desirable method for driving an electrophoretic display also reduces power consumption and image-update time while offering the required uniformity, resolution and accuracy of the images in the main window and subwindows.

One form of the present invention is a method of activating a subwindow of an electrophoretic display. Image information for a subwindow is received, an image-holding time for the subwindow including electrophoretic pixels in the subwindow is determined, and the subwindow of the electrophoretic display is addressed based on the received image information and the image-holding time.

Another form of the present invention is a system for activating a subwindow of an electrophoretic display, including an electrophoretic pixel array disposed on a backplane, means for receiving image information for the subwindow, means for determining an image-holding time for the subwindow including electrophoretic pixels in the subwindow, and means for addressing the subwindow based on the received image information and the image-holding time.

Another form of the present invention is an electrophoretic display including an electrophoretic pixel array disposed on a backplane, a row driver, a column driver and a controller connected to the row driver and the column driver. The row driver is electrically connected to a set of rows of the electrophoretic pixel array. The column driver is electrically connected to a set of columns of the electrophoretic pixel array. The controller determines an image-holding time for a subwindow of the electrophoretic display and addresses the subwindow based on the received image information and the image-holding time.

The aforementioned forms as well as other forms and features and advantages of the present invention will become further apparent from the following detailed description of the presently preferred embodiments, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the present invention rather than limiting, the scope of the present invention being defined by the appended claims and equivalents thereof.

Various embodiments of the present invention are illustrated by the accompanying figures, wherein:

FIG. 1 is an illustrative cross-sectional view of a portion of an electrophoretic display, in accordance with one embodiment of the present invention;

FIG. 2 is a schematic view of a system for activating a subwindow of an electrophoretic display, in accordance with one embodiment of the present invention;

FIG. 3 illustrates a subwindow in an electrophoretic display, in accordance with one embodiment of the present invention;

FIG. 4 shows a graph of white-state brightness for an electrophoretic display as a function of image-holding time, in accordance with one embodiment of the present invention;

FIG. 5 is a driving waveform for activating a subwindow of an electrophoretic display, in accordance with one embodiment of the present invention;

FIG. 6 is a timing diagram illustrating driving waveforms for a subwindow as a function of image-holding time, in accordance with one embodiment of the present invention;

FIG. 7 is a timing diagram illustrating driving waveforms with image-independent shaking pulses as a function of image-holding time, in accordance with one embodiment of the present invention;

FIG. 8 is a timing diagram illustrating driving waveforms with a reset pulse as a function of image-holding time, in accordance with one embodiment of the present invention;

FIG. 9 is a timing diagram illustrating driving waveforms with an image-dependent shaking pulse as a function of image-holding time, in accordance with one embodiment of the present invention; and

FIG. 10 is a flow diagram for a method of activating a subwindow of an electrophoretic display, in accordance with one embodiment of the present invention.

FIG. 1 is an illustrative cross-sectional view of a portion of an electrophoretic display **10**, in accordance with one embodiment of the present invention. Electrophoretic display **10** includes an electrophoretic pixel array **20** comprising one or more subwindows within an addressable array of electrophoretic pixels **22**.

In an exemplary embodiment, electrophoretic pixel array **20** comprises a layer of electrophoretic ink **24** disposed on a backplane **32**. Electrophoretic ink **24** may comprise one of several commercially available electrophoretic inks, commonly referred to as electronic ink or e-ink. Electrophoretic ink **24** comprises, for example, a thin electrophoretic film with millions of tiny microcapsules in which positively charged white particles and negatively charged black particles are suspended in a clear fluid. Other variants are possible, such as positively charged black particles and negatively charged white particles, or colored particles of one polarity and black or white particles of the opposite polarity, or colored particles in a white colored fluid, or particles in a gaseous fluid or colored particles in air.

The encapsulated electrophoretic particles can be rotated or translated by application of an electric field into a desired orientation. The electrophoretic particles reorient or migrate along field lines of the applied electric field and can be switched from one optical state to another based on the direction and intensity of the electric field and the time allowed to switch states. For example, when a positive electric field is applied to the display on a pixel electrode, the white particles move to the top of the microcapsules where they become visible to the user. This makes the surface appear white at the

top position or outer surface of the microcapsules. At the same time, the electric field pulls the black particles to the bottom of the microcapsules where they are hidden. When the process is reversed, the black particles appear at the top of the microcapsules, which makes the surface appear dark at the surface of the microcapsules. When the activation voltage is removed, a fixed image remains on the display surface.

Electrophoretic ink **24** may contain an array of colored electrophoretic materials to allow the generation and display of colored images such as an array of magenta, yellow, and cyan electrophoretic materials, or an array of red, green, blue and black electrophoretic materials. Alternatively, electrophoretic display **10** may include an array of colored filters such as red, green and blue positioned above black and white electrophoretic pixels. A matrix of rows and columns allows each electrophoretic pixel **22** to be individually addressed and switched into the desired optical state such as black, white, gray, or another prescribed color. Each electrophoretic pixel **22** may include one or more microcapsules, related in part to the size of the microcapsules and the included area within each pixel element.

A transparent common electrode **26** positioned on one side of electrophoretic ink **24** comprises, for example, a transparent conductive material such as indium tin oxide that allows topside viewing of electrophoretic display **10**. Common electrode **26** does not need to be patterned. Electrophoretic ink **24** and common electrode **26** may be covered with a transparent protective layer **28** such as a thin layer of polyethylene. An adhesive substance may be disposed on the other side of electrophoretic ink **24** to allow attachment to a backplane **32**. The layer of electrophoretic ink **24** may be glued, adhered, or otherwise attached to backplane **32**. Backplane **32** comprises a plastic, glass, ceramic or metal backing layer having an array of addressable pixel electrodes and supporting electronics. In an alternative embodiment, individual pixel electrodes and the common electrode may be arranged on the same substrate, whereby an in-plane electric field may be generated to move particles in an in-plane direction.

When the layer of electrophoretic ink **24** is attached to backplane **32**, individual pixel electrodes **36** on backplane **32** allow a predetermined charge **34** to be placed onto one or more electrophoretic pixels **22**. The electric field resulting from charge **34** causes transitions from one optical state to another of electrophoretic ink **24**. The electric field generates a force to re-orient and/or displace charged particles in the layer of electrophoretic ink **24**, providing a black and white or variable color display from which text, graphics, images, photographs and other image data can be presented. Gray tones or specific colors of electrophoretic ink **24** can be achieved, for example, by controlling the magnitude, level, location and timing of the activation voltage and associated charge **34**.

Addressing of electrophoretic ink **24** is accomplished by applying an activation voltage to one or more pixel electrodes **36**, placing a predetermined amount of charge **34** thereon and switching electrophoretic ink **24** to the desired optical state. Application and storage of charge **34** onto a pixel electrode **36** allows continued activation of the electrophoretic ink **24** when the activation voltage is removed, even if activation occurs on a slower time scale than the scanning process. The short-term storage effect of charge **34** on the pixel electrodes **36** allows scanning of other rows of pixels while the image continues to form in electrophoretic ink **24**. Removal of the applied activation charge **34** quenches or immobilizes electrophoretic ink **24** at the achieved optical state.

For example, electrophoretic ink **24** may be switched from white to black. In another example, an initially black optical state is switched controllably to a gray or white state. In another example, a white optical state is switched to a gray optical state. In yet another example, colored electrophoretic ink **24** switches from one color to another based on the activation voltage and the activation charge **34** applied to pixel electrodes **36**. After addressing and switching have been completed, electrophoretic displays incorporating electrophoretic ink **24** continue to be viewable with no additional power consumption.

Electrophoretic pixels **22** are addressable, for example, with a thin-film transistor array on backplane **32** and associated row and column drivers that place predetermined charge **34** onto pixel electrodes **36** of electrophoretic pixel **22** for a prescribed time to reach the desired optical state. Charge **34** is subsequently removed to retain electrophoretic pixel **22** in the acquired optical state. Intermediate values of gray can be obtained by controlling the amount of activation time and the electric field intensity across electrophoretic pixel **22**. When the electric field is removed, the particles remain in the acquired optical state, and the image written to electrophoretic display **10** is retained, even with removal of electrical power.

Sections or tiles of electrophoretic display **10** of various sizes may be assembled together or placed side-by-side to form nearly any desired size of electrophoretic display **10** that can be mounted, for example, on panels or other large surfaces. Electrophoretic display **10** may be formed with a size, for example, of a few centimeters on a side to as large as one meter by one meter or larger. Electrophoretic displays **10** with associated driver electronics may be used, for example, in monitors, laptop computers, personal digital assistants (PDAs), mobile telephones, electronic books, electronic newspapers and electronic magazines. With matrix addressing, all or part of the display may be addressed and activated, allowing portions of the display such as subwindows to be directly addressed and updated while other portions of the display retain their previously written images to reduce power consumption and extend battery life for portable applications.

FIG. 2 is a schematic view of a system **12** for activating a window or subwindow such as one or more display windows within an electrophoretic display **10**, in accordance with one embodiment of the present invention. The system includes an electrophoretic display **10** having an electrophoretic pixel array **20** containing individually addressable electrophoretic pixels **22** disposed on a display panel or backplane **32**, a controller **30**, a row driver **40**, and a column driver **50**. Row driver **40** is electrically connected via a set of row electrodes **42** to a set of rows **44** of electrophoretic pixel array **20**. Column driver **50** is electrically connected via a set of column electrodes **52** to a set of columns **54** of electrophoretic pixel array **20**. Controller **30** is electrically connected to row driver **40** and column driver **50**. Controller **30** sends command signals to row driver **40** and column driver **50** to address electrophoretic pixels **22**. A memory may be coupled to or contained within controller **30** to store items such as image data, image-independent driving waveform information, image-dependent driving waveform information, data-frame times, pixel data, subwindow sizes and locations.

Electrophoretic pixels **22** in the display or in a subwindow of the display are activated by applying an activation potential and placing a predetermined charge **34** onto one side of electrophoretic pixel **22** when electrophoretic pixel **22** is addressed by row driver **40** and column driver **50**, while common electrode **26** is biased at zero volts or at another suitable potential. Electrophoretic pixel **22** with common electrode **26** on one side and pixel electrode **36** on the other forms a capacitor that can be charged or discharged to the desired level. While charged, electrophoretic pixel **22** will transition from one optical state to another. Additional capacitance may be added in parallel with each electrophoretic pixel **22** to increase charge storage capability. In one example, row driver **40** and column driver **50** cooperate with controller **30** to supply activation voltages with a positive amplitude, a negative amplitude, or zero amplitude to selected electrophoretic pixels **22**, thereby transferring positive charge, negative charge, or no charge **34** onto the associated pixel electrodes within the subwindow.

Electrophoretic pixels **22** of electrophoretic pixel array **20** are arranged in a row-column format that allows selection of rows **44** sequentially in turn while image data corresponding to each electrophoretic pixel **22** in the selected row is placed on column electrodes **52**. Each electrophoretic pixel **22** in electrophoretic pixel array **20** is electrically connected on one side to common electrode **26** that is referenced, for example, to ground or 0 volts. A predetermined charge **34** may be placed on a pixel electrode **36** on the other side of electrophoretic pixel **22** to drive electrophoretic pixel **22** to the desired optical state. For example, a positive charge **34** placed on electrophoretic pixel **22** causes the pixel to become white, whereas a negative charge **34** placed on electrophoretic pixel **22** causes the pixel to become dark. Discharging or otherwise removal of charge **34** freezes the electrophoretic pixel at the acquired optical state.

An array of active switching elements such as thin-film transistors **38** allows the desired charge **34** to be placed on one side of electrophoretic pixel **22**. Row driver **40** is connected via row electrodes **42** to rows **44** of electrophoretic display **10**. Each row electrode **42** is connected to the gates of a row of thin-film transistors **38**, allowing transistors **38** in the row to be turned on when the row voltage is raised above a turn-on voltage. Row driver **40** sequentially selects row electrodes **42**, while column driver **50** provides data signals to column electrodes **52**. Column driver **50** is connected to column electrodes **52** of electrophoretic display **10**. Each column electrode **52** is connected to the sources of a column of thin-film transistors **38**. This arrangement of pixels, transistors **38**, row electrodes **42**, and column electrodes **52** jointly forms an active matrix. Row driver **40** supplies a selection signal for selecting a row **44** of electrophoretic pixels **22** and column driver **50** supplies data signals to the selected row **44** of electrophoretic pixels **22** via column electrodes **52** and transistors **38**.

Preferably, controller **30** first processes incoming image information **14** and generates the data signals and driving waveforms. Mutual synchronization between row driver **40** and column driver **50** takes place via electrical connections with controller **30**. Selection signals from row driver **40** select one or more rows **44** of pixel electrodes **36** via transistors **38**. Transistors **38** have drain electrodes that are electrically coupled to pixel electrodes **36**, gate electrodes that are electrically coupled to the row electrodes **42**, and source electrodes that are electrically coupled to column electrodes **52**. Data signals present at column electrodes **52** are simultaneously transferred to pixel electrodes **36** coupled to the drain electrodes of turned-on transistors **38**. The data signals and the row selection signals together form at least a portion of a driving waveform. The data signals correspond to data to be displayed, and form, together with the selection signals, a driving waveform for driving one or more electrophoretic pixels **22** in the electrophoretic pixel array **20**. The composite time for the driving waveform represents an image update period wherein a new image may be written or refreshed.

The magnitude and polarity of charge **34** placed on each electrophoretic pixel **22** depends on the activation voltage applied to pixel electrodes **36**. In one example, a negative voltage, zero voltage, or a positive activation voltage may be placed on each column such as –15V, 0V and 15V. As each row **44** is selected, charge **34** may be placed or removed from each pixel electrode **36** in the row based on the column voltage. For example, a negative charge, positive charge or zero charge may be placed on pixel electrode **36** of electrophoretic pixel **22** to switch the optical state accordingly. As the next row **44** is addressed, charges **34** on previously addressed pixels continue to reside on pixel electrodes **36** until updated with a subsequent driving waveform or are otherwise discharged.

Grayscale writing of image data to electrophoretic display **10** may be accomplished by sustaining a predetermined charge **34** on electrophoretic pixel **22** for a series of one or more data

frames. Each data frame comprises pixel data and corresponding pixel address information for each row **44** in the display. The time interval to sequentially address all rows **44** in the display once with display information constitutes the data-frame time. To supply image-independent signals to electrophoretic pixels **22** during frames, controller **30** controls column driver **50** so that all electrophoretic pixels **22** in a row **44** receive the image-independent signals simultaneously. This is done row by row, with controller **30** controlling row driver **40** in such a way that rows **44** are selected one after the other, e.g. all transistors **38** in the selected row are brought into a conducting state. To supply image-dependent signals to electrophoretic pixels **22** during a frame, controller **30** controls row driver **40** so that each row **44** is selected in turn, e.g. all transistors **38** in selected row **44** are brought into a conducting state, while controller **30** also controls column driver **50** so that electrophoretic pixels **22** in each selected row **44** receive the image-dependent signals simultaneously via associated transistors **38**. Controller **30** provides row driver signals to row driver **40** to select a specific row **44** and provides column driver **50** signals to column driver **50** to place the desired voltage level and corresponding charge **34** onto each electrophoretic pixel **22** in the selected row **44**. Controller **30** may provide data frames to selected portions of electrophoretic display **10** such as subwindows, which are described in more detail with **FIGS. 3** through **9**.

Subsequent frames may contain the same display information or updated display information with additional pixel data. The grayscale level of a specific pixel is determined by the number of consecutive frames with the same content, such as between zero and fifteen adjacent frames with a positive or negative charge **34** applied to pixel electrode **36** after electrophoretic pixel **22** has been reset to a white or black optical state. Each frame has identical data-frame times, resulting in sixteen levels of grayscale resolution per pixel.

Controller **30** processes incoming data, such as image information **14** received via image input **16**. Controller **30** detects an arrival of new image information **14** and in response starts the processing of the received image information **14**. Processing of image information **14** may include loading new image information **14**, comparing the new image information **14** to previous image information stored in a memory coupled to controller **30**, accessing memories containing look-up tables of drive waveforms, or interacting with onboard temperature sensors (not shown) to compensate for switching time variations with temperature. Controller **30** may receive image information **14** associated with a subwindow and address electrophoretic display **10** accordingly. Controller **30** detects when processing of image information **14** is ready and electrophoretic pixel array **20** can be addressed.

Controller **30**, such as a microprocessor, a microcontroller, a field-programmable gate array (FPGA), or other digital device may receive and execute microcoded instructions to address and write a desired image onto electrophoretic display **10** or a portion thereof. Controller **30** sends row selection signals to row driver **40** and data signals to column driver **50** to activate electrophoretic display **10**. Controller **30** may be contained within a personal computer (PC), a laptop computer, a personal digital assistant (PDA), an electronic book, or other digital device and connected to electrophoretic display **10**. Alternatively, controller **30** is contained within electrophoretic display **10** on backplane **32**.

Controller **30** generates the data signals that are supplied to column driver **50**, and in cooperation with row driver **40** generates row selection signals that are supplied to the set of rows **44**. Data signals supplied to column driver **50** may include an image-independent portion and an image-dependent portion. Image-independent portions of the driving waveform include signals that are identically applied to some or all of electrophoretic pixels **22** in electrophoretic pixel array **20** such as reset pulses or preconditioning pulses. Image-dependent portions of the driving waveform include image information and may or may not vary between individual electrophoretic pixels **22**.

With reference to numbered elements described in further detail in **FIGS. 3**, **4**, and **5**, controller **30** determines an image-holding time **82** for a subwindow **80** of electrophoretic display **10** and addresses subwindow **80** of electrophoretic display **10** based on received image information **14** and image-holding time **82** to activate at least one electrophoretic pixel **22** in electrophoretic pixel array **20**. Image-holding time **82** is the time interval between updating at least a portion of electrophoretic display **10** and updating subwindow **80**. Addressing and updating subwindow **80** comprises writing pixel data onto at least one electrophoretic pixel **22** in subwindow **80**. Subwindow **80** is addressed to minimize an optical-state mismatch between the addressed subwindow **80** and another portion of the electrophoretic display outside subwindow **80**.

Subwindow **80** of electrophoretic display **10** may be addressed using pulse-width modulation, activation-voltage modulation, or a combination thereof. Pulse-width modulation provides pulses of variable length such as increments of data-frame time to transition electrophoretic pixels **22** to the desired optical state. Modulation of the activation voltage, such as varying the amplitude of the negative or positive activation voltages applied to pixel electrodes **36**, affects the driving force for the electrophoretic particles and can be used to achieve additional gray levels, accuracy of gray scale, or matching to background levels within the display.

Controller **30** may generate or select a driving waveform based on image-holding time **82** for subwindow **80**. Subwindow **80** of electrophoretic display **10** may be addressed based on the generated

or selected driving waveform. The driving waveform may have an image-dependent portion having at least one data frame **70** based on received image information **14** and a current optical state of at least one electrophoretic pixel **22** in subwindow **80**. An image-dependent portion of the selected driving waveform may include an image-dependent shaking pulse. The selected driving waveform may include an image-independent portion including one or more shaking pulses prior to or after the image-dependent portion of the driving waveform. One or more reset pulses may be included in an image-independent portion of the selected driving waveform. Controller **30** selects the driving waveform from, for example, a lookup table residing in a memory within or electrically connected to controller **30**.

In one embodiment, at least a portion of the selected driving waveform is adjusted based on a scaling factor from, for example, a scaling factor table residing in memory. The scaling factor modifies the time or amplitude of the selected driving waveform to produce the desired optical state in subwindow **80**. In another embodiment, controller **30** adjusts a data-frame time **74** of one or more data frames **70** based on image-holding time **82**, and subwindow **80** of electrophoretic display **10** is addressed with data frames **70** and adjusted data-frame time **74**.

Controller **30** generates a plurality of data frames **70** from received image information **14** and addresses electrophoretic pixel array **20**. Image information **14** for subwindow **80** may be received via input **16** of controller **30**. Based on image information **14** and other input such as temperature input, controller **30** may adjust data-frame time **74** of data frames **70** to provide increased grayscale resolution and accuracy. Controller **30** determines data frames **70** based on image information **14** during image-dependent portions of the driving waveform.
Controller **30** addresses row driver **40** and column driver **50** based on pixel data and data-frame times **74** of data frames **70** to activate one or more electrophoretic pixels **22** in subwindow **80** within electrophoretic pixel array **20**. The contents of data frames **70** may be determined by controller **30** operating and executing associated code. Controller **30** provides data frames **70** including pixel data and data-frame time **74** to electrophoretic pixel array **20**. Controller **30** may send serial or parallel pixel data and data-frame times **74** of data frames **70** to row driver **40** and column driver **50** to activate electrophoretic pixels **22** within electrophoretic pixel array **20**.

Controller **30** may use one or more data frames **70** to reset electrophoretic display **10** to a predetermined optical state. After an image is written, controller **30** may address and update electrophoretic display **10** with additional data frames **70** in image-dependent or image-independent portions of the driving waveform. When an image has been written, controller **30** may power off or power down electrophoretic display **10** and associated circuitry, while electrophoretic display **10** retains the image written thereon.

Image information **14** may be provided to controller **30** from a parallel or serial connection with a digital computing device, video camera, or other source of display information. With reference to numbered elements described in more detail with **FIG. 5**, the provided display data may include pixel data and data-frame time **74** with each data frame **70**. Alternatively, controller **30** may generate pixel data and data-frame time **74** for each data frame **70** after receiving image information **14** in any suitable display format.

With a high clock speed, controller **30** may adjust data-frame time **74** of data frame **70** to provide increased grayscale resolution and increased accuracy. Electrophoretic display **10** is reset, for example, to a predetermined optical state such as all black, all white, or a pre-specified color or gray level by addressing and switching each electrophoretic pixel **22** in electrophoretic pixel array **20**. With subsequently provided image information **14**, electrophoretic display **10** may be updated with additional pixel data by addressing and writing onto electrophoretic pixels **22** in electrophoretic display **10**. When electrophoretic display **10** is not addressed or a portion or all of system **12** is powered down or powered off, electrophoretic display **10** retains and displays the previously written image.

To account for temperature changes within the display and to mitigate variations in switching time with temperature, a temperature sensor (not shown) may be included on or near backplane **32**. Temperature effects may be compensated, for example, by scaling data-frame times **74** in accordance with the current operating temperature of electrophoretic display **10**.

FIG. 3 illustrates a subwindow **80** in an electrophoretic display **10**, in accordance with one embodiment of the present invention. Subwindow **80** comprises a portion of electrophoretic display **10**, as might be used with a personal digital assistant (PDA), a mobile telephone, an electronic dictionary or an electronic book.

An exemplary subwindow **80** comprises a square or rectangular region including and surrounding an object such as a cursor, a selection arrow, a mouse icon or a sized application window. As subwindow **80** is moved or resized, electrophoretic display **10** is locally updated in subwindow **80** along with newly exposed portions of the background or other windows. Multiple subwindows **80** may be imaged with electrophoretic display **10**, such as with menu bars, selection icons, or separate subwindows **80** for one or more applications being displayed simultaneously on electrophoretic display **10**.

FIG. 4 shows a graph of white-state brightness for an electrophoretic display as a function of un-powered image-holding time, in accordance with one embodiment of the present invention. A characteristic brightness curve **84** for an electrophoretic ink shows an initial brightness at time t_a representing a white optical state. When the electrophoretic ink is activated, the brightness is at its

highest level. When power is removed, the image continues to be displayed, although the intensity or brightness decays over time. As time progresses, the brightness decreases along brightness curve **84**. At time t_b, the brightness has decreased towards a gray level. As time passes without refreshing through time t_c, t_d and t_e, the brightness continues to decrease until the display is refreshed or updated. A high frequency of refreshing or updating of a portion or all of the electrophoretic display results in consistently high brightness and consistent gray levels. However, for low power applications such as portable displays, infrequent display updates and the activation and updating of only selected portions can appreciably reduce power consumption requirements, a desirable attribute for extending battery life.

When a portion of the display is updated while other portions have decayed, the optical states of the updated and non-updated portions may be mismatched and visible to the viewer. Optical state mismatch may be minimized by activating pixels in subwindow of the display to optically match the brightness of surrounding pixels. One way of achieving this is to determine the amount of time since the previous display update, and transition the pixels in the subwindow to an optical state that matches the brightness of surrounding pixels. Following along brightness curve **84**, when an amount of image-holding time **82** corresponds to, for example, time t_d, then the optical state written to pixels in the subwindow are adjusted to match the decayed brightness, thereby avoiding ghosting, remnant images, and other optical affects. Further improvements may be achieved by matching the decay rate as well as the time-dependent brightness.

FIG. 5 shows one example of a driving waveform for activating a subwindow in an electrophoretic display, in accordance with one embodiment of the present invention. **FIG. 5**, which is described with reference to numbered elements of **FIGS. 1** through **4**, illustrates a driving waveform **60** for activating electrophoretic display **10** with data frames **70** in an image-dependent portion of driving waveform **60**. Driving waveform **60** represents voltages across electrophoretic pixel **22** in electrophoretic display **10** as a function of time *t*. Driving waveform **60** is applied to electrophoretic pixels **22** using row selection signals from row driver **40** and data signals supplied via column driver **50**. Driving waveform **60** comprises, for example, a column driving signal and a row selection signal for providing preconditioning or shaking pulses, one or more reset signals, and data signals associated with each optical state and transitions thereto. Data frames **70** are applied in an image-dependent portion of driving waveform **60** represented by data frames **70a**, **70b**, **70c**, **70d**, **70e** and **70f**. Data frames **70** may also be introduced into image-independent portions of driving waveform **60**, such as a preconditioning portion **62** and a reset portion **64**.

Driving waveform **60** comprises multiple data frames **70**, including an image-dependent portion with a plurality of data frames **70**. Driving waveform **60** also includes an image-independent portion comprising, for example, one or more preconditioning portions **62**, reset portion **64**, or a combination thereof. The timing for image-dependent data frames **70**, preconditioning portions **62**, and reset portions **64** is intended to be illustrative and is not necessarily drawn to scale. Data-frame time **74** is the time interval required to address pixels of all rows **44** once by driving each row one after the other and by driving all columns **54** simultaneously once per row. During each data frame **70**, image-dependent or image-independent data is supplied to one or more electrophoretic pixels **22** in the array. Driving waveform **60** comprises, for example, a series of shaking pulses in preconditioning portion **62** followed by a series of reset pulses in reset portion **64**, another set of shaking pulses in another preconditioning portion **62**, and a combination of driving pulses to drive electrophoretic pixel **22** into the desired optical state.

For example, an electrophoretic display **10** with four gray levels may have sixteen different driving waveforms **60** stored in a lookup table in a memory that is electrically connected to or part of controller **30**. From an initial black state, four different driving waveforms **60** allow the initially black pixel to be optically switched to black, dark gray, light gray, or white. From an initially dark-gray state, four different driving waveforms **60** allow the initially dark-gray pixel to be optically switched to black, dark gray, light gray, or white. Additional driving waveforms **60** allow a light gray or a white pixel to be switched to any of the four gray levels. In response to image information **14** received via image input **16**, controller **30** may select the corresponding driving waveform **60** from a lookup table for one or more electrophoretic pixels **22**, and supply the corresponding row selection signals and column data signals via row driver **40** and column drivers **50** to corresponding transistors **38** connected to corresponding pixel electrodes **36**. To match the optical states of background pixels, the driving waveforms **60** for driving electrophoretic pixels **22** within subwindow **80** may be adapted.

To reduce the dependency of the optical response of electrophoretic display **10** on the image history of the pixels, preconditioning signals may be applied to electrophoretic pixels **22** prior to the application of reset signals or image-dependent signals. Preconditioning allows electrophoretic pixels **22** to switch faster with higher uniformity of transitions between one optical state and another. During preconditioning portions **62** of driving waveform **60**, alternating pulses of positive and negative voltage, sometimes referred to as shaking pulses **66**, are applied to one or more electrophoretic pixels **22** of the display in preparation for subsequent optical state transitions. For example, a set of alternating positive and negative voltages is applied sequentially to the pixels. These preconditioning signals may comprise applying alternating voltage levels to electrophoretic pixels that are sufficient to release the

electrophoretic particles from a static state at one or both electrodes, yet either sum to zero or are too short to significantly alter the current positions of the electrophoretic particles or the optical state of the pixel. Because of the reduced dependency on the image history, the optical response of pixels to new image data are substantially independent of whether the pixel was previously black, white or gray. The application of the preconditioning signals reduces the dependency and allows a shorter switching time.

For example, during the initial portion of driving waveform **60**, a first set of frames comprising the pulses of the preconditioning signals are supplied to the pixels, each pulse having a duration of one frame period. First shaking pulse **66** has a positive amplitude, second shaking pulse **66** has a negative amplitude, and third shaking pulse **66** has a positive amplitude with additional pulses in an alternating sequence until preconditioning portion **62** is completed. As long as the duration of these pulses is relatively short or the pulses are applied in rapidly changing positive and negative levels, the pulses do not change the gray value displayed by the pixel. A shaking pulse is generally defined as a voltage pulse representing energy sufficient to release the electrophoretic particles from the current state at one or both electrodes though insufficient to bring the particles from one of the extreme positions near the electrodes to the other extreme position near the other electrode.

During reset portion **64** of driving waveform **60**, electrophoretic display **10** is reset to a predetermined optical state, such as an all-black state, an all-white state, a gray-scale state, or a combination thereof. The reset pulses within reset portion **64** precede the image-dependent pulses to improve the optical response of electrophoretic display **10** by defining a fixed starting point such as black, white, or an intermediate gray level for the image-dependent pulses. For example, the starting point is selected based on previous image information or the closest gray level to new image data. A set of frames comprising one or more frame periods is supplied including pixel data associated with the desired optical state. The activation voltage and activation charge **34** may be applied for a time longer than is required to fully switch the addressed portions of electrophoretic display **10** to the initialized optical state, and then may be removed. Alternatively, electrophoretic display **10** may be reset with a positive or a negative voltage applied to common electrode **26** while pixel electrodes **36** are maintained at a low voltage or ground potential. To set electrophoretic pixels **22** at the desired optical state, adapted data frames **70** may be used.

After reset portion **64** of driving waveform **60** has been applied, electrophoretic pixels **22** appear in the predetermined optical state to the viewer. An additional preconditioning portion **62** may be applied to one or more electrophoretic pixels **22** after application of reset portion **64** in preparation for writing or updating an image to the display. Prior to addressing the display with image-dependent

data, an additional preconditioning portion **62** may be added after reset portion **64** to prepare the pixels for receiving image-dependent frame data.

During the image-dependent portion of driving waveform **60**, a set of data frames **70** comprising one or more frame times or periods is generated and supplied. The image-dependent signals have duration, for example, of zero, one, two, through fifteen frame periods or more with non-zero data signals corresponding to sixteen or more grayscale levels. When starting with a pixel in a black optical state, an image-dependent signal having a null pixel data or equivalently a duration of zero frame periods corresponds with the pixel continuing to display black. In the case of a pixel displaying a specific gray level, the gray level remains unchanged when being driven with a pulse having a duration of zero frame periods, or with a sequence of pulses having zero amplitude. An image-dependent signal having a duration of fifteen frame periods comprises fifteen subsequent pulses and corresponds to, for example, the pixel transitioning to and displaying white. An image-dependent signal having a duration of one to fourteen frame periods comprises one to fourteen subsequent pulses and corresponds to, for example, the pixel displaying one of a limited number of gray values between black and white.

Electrophoretic display **10** is updated with image information converted and applied as pixel data to each pixel in the display on a row-by-row basis with one or more data frames **70**, represented as data frames **70a**, **70b**, **70c**, **70d**, **70e** and **70f**, each having pixel data. In the example shown, data-frame times of data frames **70a** through **70f** are constant. Data-frame times **74** associated with data frames **70** may be adjusted to provide increased grayscale resolution and accuracy. Controller **30** may adjust data-frame time **74** of any frame in driving waveform **60** to improve the grayscale resolution or to reach a specific gray level, such as by delaying the start of a frame period and thereby extending the preceding frame time, by adjusting the number of clock cycles between the start of a row selection signal and the start of the next row selection signal, or by adjusting the overall system clock speed as applied to row driver **40**.

Electrophoretic display **10** may be updated with additional pixel data supplied with subsequently applied driving waveforms **60**. For example, to update electrophoretic pixels **22** in electrophoretic display **10**, a row selection signal is applied sequentially to each row **44** of the display, while pixel data for electrophoretic pixels **22** in each row is applied to columns **54** connected to pixel electrodes **36**. Positive charge, negative charge, or no charge is transferred onto pixel electrodes **36** in accordance with the frame data, and electrophoretic pixels **22** respond accordingly with a darker state, a lighter state, or no change.

To activate electrophoretic display **10**, controller **30** may execute a computer program to convert image information into a series of driving waveforms **60** and address the display accordingly.

The computer program includes computer program code to receive image information **14** for subwindow **80**, to determine an image-holding time **82** for subwindow **80**, and to address subwindow **80** of electrophoretic display **10** based on the received image information **14** and image-holding time **82**. The computer program may also contain computer program code to select a driving waveform **60** based on image-holding time **82** for subwindow **80**, and to address subwindow **80** of electrophoretic display **10** based on the selected driving waveform **60**. The computer program may contain computer program code to adjust selected driving waveform **60** based on a scaling factor from a scaling factor table, or to adjust a data-frame time **74** of at least one data frame **70** based on image-holding time **82**, and addressing subwindow **80** of electrophoretic display **10** with data frames **70** and adjusted data-frame time **74**.

FIG. 6 is a timing diagram illustrating driving waveforms **60** for a subwindow as a function of image-holding time **82**, in accordance with one embodiment of the present invention. Driving waveforms **60**, represented by driving waveforms **60a**, **60b**, **60c**, **60d** and **60e**, may be selected based on image-holding time **82** for subwindow **80** as described with respect to **FIG. 4**. In the cases shown, a black pixel transitions to a white pixel to match a white background. Driving waveform **60a** is selected for the case where one or more pixels in subwindow **80** are updated coincidently with or immediately following a complete screen refresh or display update to match the brightness level of the white background. As time increases after the screen update, driving waveform **60b** may be used to transition a black pixel to a slightly darker white pixel to match the slightly less-than-white background. As may be observed by close inspection, the number of frames for the negative voltage pulses is reduced from driving waveform **60a** so that a slightly less white state is obtained. With a further increase in time after the screen update, driving waveform **60c** may be used to transition a black pixel to an even slightly darker white pixel that matches the slightly more decayed and darker white background. The number of frames for the negative voltage pulses is reduced from the driving waveform **60a** and **60b**. With a further increase in time after the screen update, driving waveforms **60d** and **60e** may be used to transition a black pixel to an optical state that matches the decayed white background.

FIG. 7 is a timing diagram illustrating driving waveforms **60** with image-independent preconditioning or shaking pulses **66** in a preconditioning portion **62** as a function of image-holding time, in accordance with one embodiment of the present invention. Preconditioning portion **62** aids in preconditioning the electrophoretic ink for rapid and accurate transitions to the desired optical state and may be positioned prior to activation voltages of driving waveforms **60a**, **60b**, **60c**, **60d** and **60e**, as discussed in reference to **FIG. 6**.

FIG. 8 is a timing diagram illustrating driving waveforms **60** with reset pulses of reset portion **64** as a function of image-holding time, in accordance with one embodiment of the present invention. Reset pulses of reset portion **64** aid in resetting one or more electrophoretic pixels to a prescribed initial state such as an all-white or all-black optical state prior to application of driving waveforms **60a, 60b, 60c**, **60d** and **60e**, as discussed in reference to **FIG. 6**.

FIG. 9 is a timing diagram illustrating driving waveforms **60** with one or more image-dependent shaking pulses **66** as a function of image-holding time, in accordance with one embodiment of the present invention. Image-dependent shaking pulses **66** may be positioned symmetrically or asymmetrically within driving waveforms **60** to slow or otherwise mitigate the decay affect, allowing both the brightness and decay rate to be matched with the background for driving waveforms **60a, 60b, 60c**, **60d** and **60e**, as discussed in reference to **FIG. 6**.

FIG. 10 is a flow diagram for a method of activating one or more subwindows of an electrophoretic display, in accordance with one embodiment of the present invention. The activation method includes exemplary steps to activate a subwindow of an electrophoretic display.

Image information is received, as seen at block **90**. Image data may be received from a memory device such as a memory stick, or an uplink from a PC, laptop computer or PDA that is optionally connected to a controller electrically coupled to the electrophoretic display. Image information may be received via a wired or wireless link from any suitable source such as a video feed, an image server, or a stored file. The controller may be connected to a communications network such as a local area network (LAN), a wide-area network (WAN), or the Internet to receive and send information and to transfer images onto the electrophoretic display. The image information may be provided in real time as the image is written to the electrophoretic display, or stored within memory until written. When image information is received, the image data may be processed to generate and provide a plurality of data frames including pixel data and data-frame times to address and activate a subwindow of the electrophoretic display.

An image-holding time for the subwindow is determined, as seen at block **92**. Determining the image-holding time comprises determining the time interval between updating at least a portion of the electrophoretic display and addressing the subwindow of the electrophoretic display.

To update a subwindow, a driving waveform may be generated or selected based on the image-holding time for the subwindow. The driving waveform may be selected from, for example, a lookup table stored in memory.

In one embodiment, the driving waveform is selected based on the image-holding time for the subwindow, and the subwindow is addressed based on the selected driving waveform. The selected

driving waveform may include an image-dependent portion having at least one data frame based on the received image information and a current optical state of at least one electrophoretic pixel in the subwindow. The image-dependent portion of the selected driving waveform may include one or more image-dependent shaking pulses. An image-independent portion of the selected driving waveform may include one or more image-independent shaking pulses. An image-independent portion of the selected driving waveform may include one or more reset pulses.

In another embodiment, the driving waveform at a reference image-holding time (such as at time t_a in **FIG. 4**) is selected for the subwindow, and the selected driving waveform is adjusted based on a scaling factor for the subwindow image-holding time from, for example, a scaling factor table.

In another embodiment, a data-frame time of at least one data frame is adjusted based on the image-holding time, and the subwindow is addressed with the data frames and the adjusted data-frame time to activate the subwindow. The data-frame time of one or more data frames may be adjusted to provide increased grayscale resolution, increased accuracy, and matching of optical states within the subwindow to portions of the electrophoretic display external to the subwindow. Alternatively, the activation-voltage amplitude of one or more data frames may be adjusted to provide the desired levels and optical matching.

In another embodiment, the number of data frames in the selected driving waveform is adjusted based on the image-holding time as a form of pulse-width modulation, and the subwindow is addressed with the adjusted waveform to activate the subwindow. In another embodiment, the activation-voltage amplitude of the selected driving waveform is adjusted based on the image-holding time as a form of activation-voltage modulation, and the subwindow is addressed with the adjusted waveform to activate the subwindow.

The subwindow of the electrophoretic display is addressed, as seen at block **94**. The subwindow is addressed based on the received image information and the image-holding time. Addressing the subwindow of the electrophoretic display comprises, for example, writing pixel data onto at least one electrophoretic pixel in the subwindow. The subwindow of the electrophoretic display is addressed to minimize an optical-state mismatch between the addressed subwindow and another portion of the electrophoretic display such as the background, the main window, or another subwindow.

Data frames may include null pixel data when no change to the optical state of the associated pixels is desired. Alternatively, pixel data corresponding to positive or negative activation voltages and positive or negative charge on the pixel electrodes may be used to activate the electrophoretic ink within the subwindow to provide increased grayscale resolution, accuracy, and grayscale matching.

The subwindow of the electrophoretic display may be addressed using pulse-width modulation, activation-voltage modulation, or a combination thereof.

When the electrophoretic display is addressed and an image is transferred to the electrophoretic display, an activation voltage is applied to one or more electrophoretic pixels and a predetermined charge is placed on corresponding pixel electrodes based on the pixel data and the data-frame times. The activation voltage is selected to switch selected portions of the electrophoretic display from the reset state or a previous optical state to the desired optical state. As charge is placed on pixel electrodes, the electrophoretic ink is activated and switches to the desired optical state. When the predetermined charge is placed across the pixels of the electrophoretic display, the electrophoretic ink continues to transition to an intended display state as long as the activation voltage is applied or the applied charge is retained on a pixel electrode. Based on the number, length and content of data frames, the electrophoretic ink is provided sufficient time to switch optical states in the designated pixels. The desired optical state for the electrophoretic display can be locked in or frozen by removal of the activation charge and the activation voltage from pixels in the display.

Driving waveforms containing one or more data frames may be generated or selectively extracted, for example, from a lookup table stored in memory and provided to the electrophoretic display. The driving waveforms may contain image-dependent data frames selected to transition the electrophoretic pixels to the desired optical state and compensated for the image-holding time. The driving waveforms may contain image-independent data frames including one or more shaking pulses or one or more reset pulses.

The subwindow of the electrophoretic display may be preconditioned and/or reset to a predetermined optical state. Before the subwindow is addressed, electrophoretic ink of the display material may be reset to a well-defined state. The electrophoretic ink can be forced into an initialized or reset optical state through an applied electric field with, for example, the sustained application of relatively high activation voltage applied to electrophoretic pixels within the subwindow via the pixel electrodes. When the electrophoretic display is reset, one or more pixels in the subwindow are reset to the predetermined optical state, such as an all-white, all-black, gray, or colored optical state, depending on the type of electrophoretic ink and the applied activation voltage. From this reset optical state, the electrophoretic ink can be adjusted in one common direction or another based on the driving forces applied to the electrophoretic pixels. Alternatively, the subwindow of the electrophoretic display may be reset with a pattern similar to the image to be written, so that only a fraction of the total switching time for the electrophoretic ink is needed to write the image in the subwindow with the desired grayscale

resolution and accuracy. Similar to the data-dependent portion of the driving waveform, the electrophoretic display may be reset with a plurality of image-independent data frames including pixel data and data-frame times.

Prior to, in conjunction with or as an alternative to resetting the display, the subwindow of the electrophoretic display may be preconditioned with the application of one or more shaking or preconditioning pulses. Shaking pulses are applied to the electrophoretic pixels in the subwindow to precondition the electrophoretic pixels for receiving pixel data or for switching to a reset state. The electrophoretic ink is preconditioned, for example, with the application of an alternating activation voltage applied to pixel electrodes in the subwindow of the display. After resetting the subwindow and prior to writing an image, the subwindow may be preconditioned once again with the application of additional shaking pulses.

After the desired image has been written to the electrophoretic display, the image may be viewed. Further refreshing or writing of new images may occur as desired within, for example, a portion of a second, minutes, hours, days, weeks or even months after writing previous images.

The electrophoretic display may be refreshed or updated with additional image information and pixel data, as seen at block **96**. New image data may be received, and the electrophoretic display updated accordingly by repeating the above steps of blocks **90** through **94**. Alternatively, the display may require refreshing with stored image information, and previous image data may be re-sent to the display.

When no refreshing or updating of the image is required, circuitry may be powered down or turned off, the electrophoretic display may be powered off or otherwise placed in a power-down mode, as seen at block **98**. When powered off or powered down, the electrophoretic display retains the image previously written to the display, unless written over with a black, white or other predetermined screen image.

While the embodiments of the invention disclosed herein are presently considered to be preferred, various changes and modifications can be made without departing from the spirit and scope of the invention. The polarity of preconditioning and reset voltages, the data-frame times, the length of the driving waveform and the order of the portions included thereof, the number of gray levels, the size and number of pixel elements, the color of electrophoretic ink, and the thickness of the various layers have been chosen to be illustrative and instructive. The activation voltages, timing, color of the electrophoretic ink, scale and relative thickness of the included layers, pixel size, array size, driving waveforms and other signals and quantities may vary appreciably from that which is shown without departing from the spirit and scope of the claimed invention. This invention is applicable to other bi-

stable displays. The scope of the invention is indicated in the appended claims, and all changes that come within the meaning and range of equivalents are intended to be embraced therein.